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The Hall Scale Eradication Project [1]

By E. H. Fosen, *(agent) agriculturist, Region IV,* and A. W. Cressman, *entomologist, Division of Fruit Insect Investigations, Bureau of Entomology and Plant Quarantine, Agricultural Research Administration,* and H. M. Armitage, *chief, Bureau of Entomology, California Department of Agriculture.*

CONTENTS

INTRODUCTION

The Hall scale (*Nilotaspis halli* (Green)) was discovered in the United States in the U. S. Plant Introduction Garden at Chico, Calif., by C. F. Kinman in 1934. It was first found on *Prunus bokhariansis* and subsequently on many additional species and varieties of *Prunus* and *Amygdalus*. Upon discovery of the scale, host plants that had been shipped from the Plant Garden that season were located and destroyed. Inspection of many of the host plants shipped to various points in California from 1928 through 1933 gave negative results, and it was decided to attempt eradication of the infestation in the Plant Garden (Mackie *11*).[2] Many trees were pulled and burned. Treatment of the remainder included cutting back to scaffold branches, scraping the bark, painting with oil emulsion, fumigating with hydrocyanic acid gas, and applying a special tree paint (fig. 1). Fumigation was at the rate of 2.5 ounces or more of sodium cyanide per 100 cubic feet

[1] The work described in this circular was established as a Federal-State cooperative project by the U. S. Bureau of Entomology and Plant Quarantine and the California Department of Agriculture, under the respective supervision of D. L. Van Dine and the late D. B. Mackie. It was subsequently organized and directed by B. L. Boyden of the Bureau in cooperation with Mackie until 1945. Contributions of V. R. Jones, in charge of fumigation, H. W. Gray, in charge of inspection, and H. J. Crawford, in charge of biological studies, and the technical assistance of H. R. Yust and R. A. Fulton in developing fumigation procedure are acknowledged. The first four photographs were taken by Cliff Clower, of the California Department of Agriculture.

[2] Italic numbers in parentheses refer to literature cited, p. 16.

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FIGURE 1.—Treatment of trees infested with the Hall scale in the Plant Introduction Garden, Chico, Calif., in 1935.

for 1 hour under double untreated canvas or rubberized covers. Some scales survived this procedure, and treatment or removal of them was continued until the infestation was thought to be eradicated.

However, in an insect survey of the Chico area in 1940, the scale was found again—in an almond orchard adjoining the Plant Garden, and later in the garden. As a result, a joint Federal-State project was organized in 1941 to determine the area infested and investigate the possibility of eradication. This circular summarizes information on the biology and habits of the Hall scale and the progress made in determining the area of infestation and eradicating the scale.

DISTRIBUTION

The Hall scale was described from Egypt by Green (*8*). Mackie (*10*) learned through correspondence that it was found in Turkey and Tripoli and that it was common over all lower Egypt. It is also recorded from Afghanistan (Archangelskaya *1*), U. S. S. R. (Turkmenia, Uzbekistan, and Tadzhikistan) (Borchsenius *4*), Greece (Koroneos *9*), Iraq (Bodenheimer 2, *3*), and Baluchistan.[3] Specimens from Syria, Iran, and Israel have also been identified by the U. S. Bureau of Entomology and Plant Quarantine. The place of origin and the time of its introduction into the United States are unknown.

After the infestation was discovered near Chico, in Butte County, infestations were found in Oroville and Davis, Calif. All the evidence indicates that the infestation in the Plant Introduction Garden at Chico was the source of the other infestations. Although there had been considerable movement of host plants out of the Plant Garden to other parts of California

[3] Personal communication from A. M. Boyce, University of California Citrus Experiment Station, Riverside, Calif. Specimens identified by H. L. McKenzie, California Department of Agriculture, Bureau of Entomology.

and the United States before the original infestation was discovered, a subsequent survey has failed to show that they carried any infestation. Since the discovery of the scale, all hosts have been vacuum-fumigated before being permitted to leave the garden.

HOST PLANTS AND INJURY

The hosts on which the scale has been found in this country are limited to the genera *Prunus* and *Amygdalus*, and the shrub *Spireae veitchii*. Preferred hosts include almonds, peaches, nectarines, plums, and prunes (fig. 2, 3). Pomegranate (*Punica granatum*) is recorded as a host in the literature

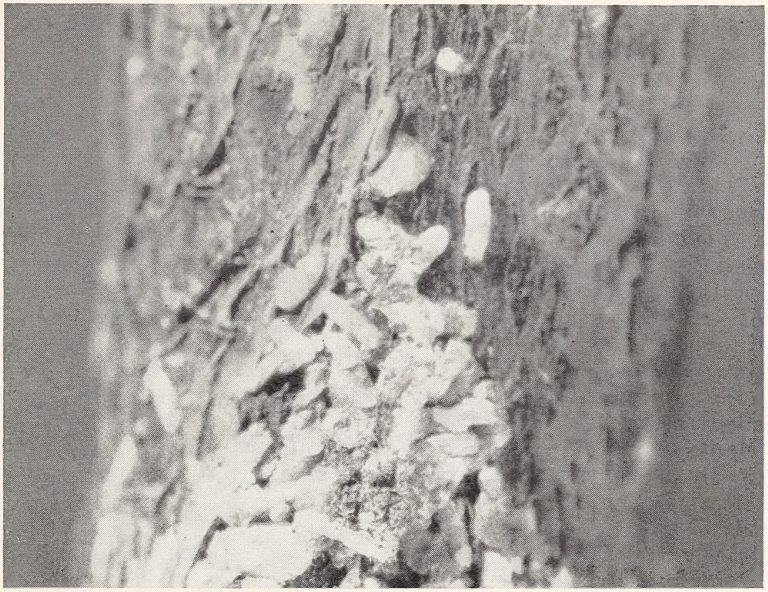

FIGURE 2.—Hall scale on a prune twig. (X12)

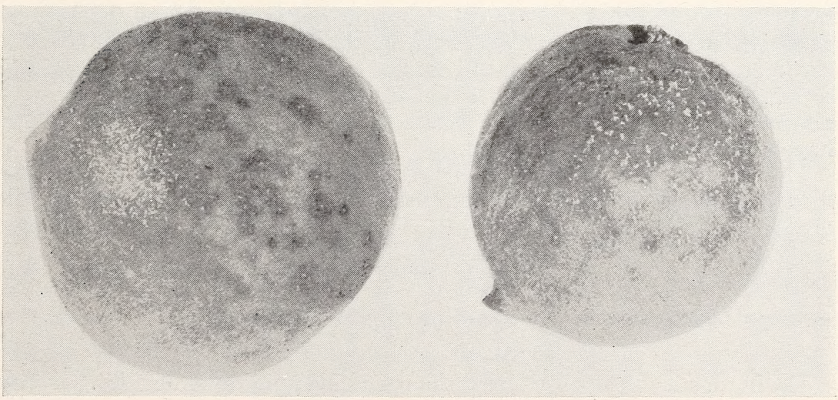

FIGURE 3.—Hall scale on peaches, showing blotches caused by scales.

(Archangelskaya *1*), but has not been found infested in the United States even when adjacent to heavily infested trees. Additional hosts recently reported include *Pyrus*, *Malus*, *Cydonia vulgaris*, and *Cerasus* (Borchsenius *4*).

The scale is a potentially serious pest. In addition to its weakening effect on the tree, the insect's tendency to migrate to and develop on the fruit may cause severe injury to some fruits. The scale causes conspicuous blotches on peaches (fig. 3), nectarines, and plums. When the infestation at Davis was discovered, it was estimated that 25 percent of the peach crop was damaged even though the trees had been sprayed with oil the preceding winter. The hulls of almonds may become heavily infested, but no damage to the nuts has been discovered. Although every infestation was intensively treated as soon as discovered, feasible observations suggest that the most important injury may result from infestation on the fruit.

DESCRIPTION OF STAGES AND HABITS

The Hall scale is ovoviviparous. The oval, pale-yellow crawlers are about 0.23 by 0.12 mm. After a short period of activity, the crawlers settle, insert their mouth parts into the host tissue to feed, secrete a protective waxy covering, and gradually increase in size. The females molt twice and the males three times. Only the adult males have wings. Mating takes place soon after the females have gone through the second molt.

The cover of the adult female scale is elongate-oval, about 1.08 by 0.44 mm., and usually creamy tan with the orange exuvium of the second stage at one end. The body is a pale yellow. The male covering develops in the second instar as a narrow scale, with nearly parallel sides, thinner texture, and lighter color, whereas the female scale is more oval, denser, and darker. The male completes its development to winged adult beneath this narrow cover.

The young scales settle on all parts of the host. Generally the males outnumber the females on foliage, fruit, and twigs of the current season's growth, but more females are present on other parts of the trees. Field observations indicate that the two sexes are present in nearly equal numbers. Many crawlers, especially the females, settle in protected places, such as deep crevices in wood, under loose bark, and under bud scales. This habit makes both inspection and control difficult. During the spring and summer there is also considerable movement from the trunk and larger branches to the current year's twig growth, leaves, and fruit. For example, 1,812 scales have been found on 1 almond hull and 1,962 on a current-growth almond twig 22 inches long. Fruits of peaches, nectarines, and prunes have also become heavily infested.

The reproductive capacity of the females could not be determined from field observations. The maximum number of ova and embryonic cells observed in a single female was 74. The total progeny might well exceed the number of ova seen at any one time.

SEASONAL HISTORY

During January the only live scales found are nongravid females. A few gravid stages have been found in February, and most of them are gravid

in April. The crawlers begin to emerge in April or late in March. A further chronology of field observations is as follows:

May 13	first molt
20	males recognizable
June 24	second molt of females; males emerged
July 26	gravid females on current growth
August 7	nearly spent females on current growth
October 16	last crawlers and last males found; live scales in all stages present
December 16	last gravid females found

Crawler emergence generally reaches a peak in May or June, before the summer sprays are applied. In the absence of a summer-oil spray, emergence might continue at a high rate throughout the summer. The finding of emerged males by June 24, gravid females by July 26, and nearly spent females by August 7, all on current season's growth, shows that there is at least a partial second generation in the summer.

ERADICATION PROGRAM

When the eradication project was undertaken in 1941, the following program was adopted:

(1) Repeated applications of oil sprays to reduce the scale population on known infested properties and decrease the danger of spread while other work was being carried on.

(2) Survey of the Chico area to locate infestations resulting from movement of host plants from the Plant Garden.

(3) Intensive inspection within 2 miles of known infested properties. This distance was tentatively set as the limit of natural spread. As information was developed, it was later reduced to 1 mile.

(4) Location and inspection of host material shipped from the plant garden to points outside the Chico area before 1934, when a fumigation procedure for treatment of all hosts being sent out of the garden was established.

(5) Removal of heavy growth along creeks running through infested properties to reveal and permit removal and destruction of host seedlings.

(6) Field tests of oil sprays, both alone and with added toxicants, and of hydrocyanic acid gas fumigation, to develop an eradication treatment. As a result, an effective treatment consisting of fumigation with hydrocyanic acid gas under gastight tents was developed. The treatment program includes provision for the following:

(a) A spring and an early fall spray of light medium oil applied each year beginning with the discovery of an infestation, and continuing to completion of the fumigation program, to suppress an infestation until fumigation can be started and to supplement fumigation during the subsequent treatment period.

(b) Annual fumigations with hydrocyanic acid gas for 3 consecutive years after the last finding of live scales.

(c) Several annual intensive inspections to check results of treatment after the final fumigation.

Survey and Inspection

All properties in an irregular area approximately 15 miles long and 12 miles wide surrounding the city of Chico, containing approximately 800,000 host plants, mostly almonds, were scheduled for inspection. The area is isolated from other fruit-growing sections by grain, pasture, and open range land. The movement of infested plant material was considered to be the most likely means of spread to these properties.

It was found that any material obtained from the Plant Garden was likely to be planted near houses or other buildings or along roadways

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where it could be easily observed. Therefore, the first inspections were limited to host plants in yards and spot examination of other plants near buildings and roadways on properties outside the intensive-inspection zones. Every property within the area was inspected in this manner. The owner of the property was questioned to find out whether he had received Plant Garden material and if he had his property was scheduled for future reinspection.

In reinspections, hosts from the Plant Garden, as well as adjacent hosts, were included. If the Plant Garden hosts had been removed, all host plants within approximately 50 feet of the former location were checked. If the owner did not have any information on the location of the host plants, every host on the property was examined. Two infested areas where scales were not found in the first inspection were located by reinspection of properties of recipients of suspected material.

As inspection progressed, it was found that the build-up and spread of the scale were slow, that natural spread was limited to the immediate vicinity of infestations, and that any infestation found outside this restricted area would probably be due to movement of infested material from the garden. Therefore, the original plans with reference to inspection of properties near known infestations were modified. The probable area of natural spread was redefined to include the area within ¼ mile of known infested properties. Within this area orchards adjacent to infestations were given a tree-to-tree inspection and at least one-fourth of the trees in other orchards were inspected. Inspections were made from the ground and from ladders, and were supplemented by microscopic examination in the laboratory of large numbers of randomly collected twigs. This program was carried out at least twice in much of the intensive inspection area.

Until the discovery of a long-standing infestation near Bidwell Park in 1949, natural spread appeared to be limited to properties adjacent to previously infested properties. In the Bidwell Park area infestations were found more than ½ mile from any other infestation. The intensive inspection was then extended to include the area within 1 mile of all known infestations. The intensity of inspection outside the ¼-mile area previously inspected, varied with the degree of the earlier infestation and the time since the area had been put under treatment. In Chico and nearby towns every host plant was inspected.

The U. S. Bureau of Plant Industry furnished a list of all shipments of host material from the Plant Garden made from 1928 to 1934. Shipments made during these 6 years were selected as representing a large sample of the material sent out. They contained material most likely to be infested, since the infestation could be expected to increase from the time of establishment until discovery in 1934. All the material that could be located in the Pacific Coast and adjacent States and in the Gulf States was inspected with negative results. These regions were selected as the ones likely to be most favorable to the establishment of new infestations. The entomologists of the States concerned cooperated in this work, and some of the inspections were made entirely by State personnel. Inspections in California were made by County, State, and Federal employees.

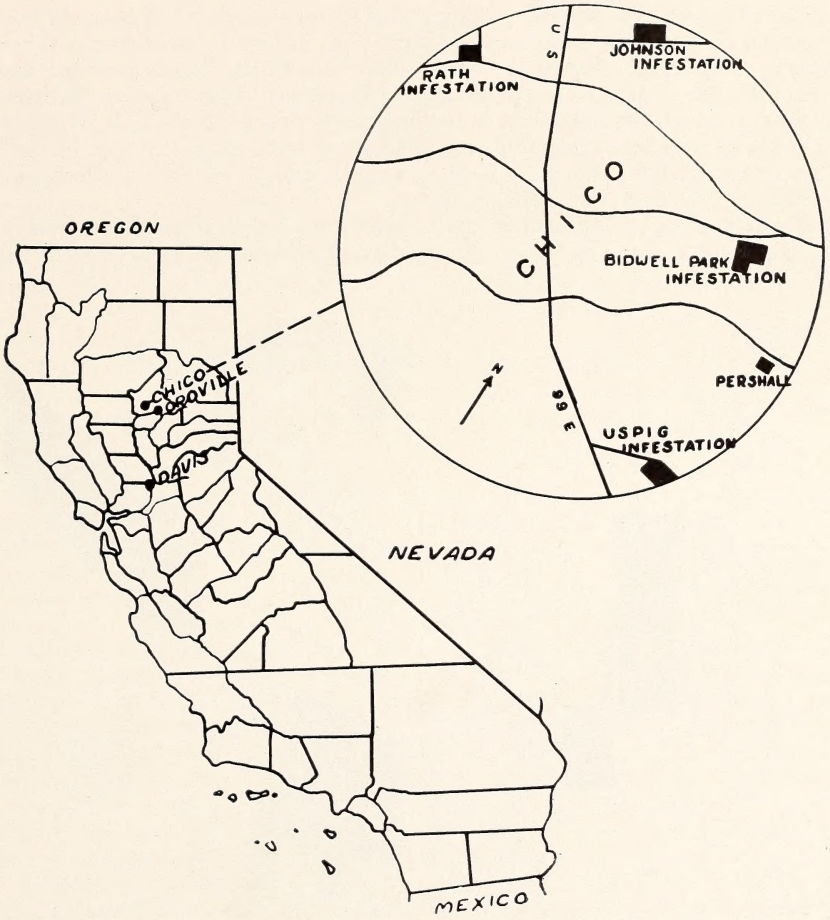

FIGURE 4.—Hall scale infestations in the United States, with enlargement of the Chico, Calif., area.

Figure 4 shows the infested areas, all in California. The approximate numbers of host plants in these areas were as follows:

Chico:	
United States Plant Introduction Garden	15,000
Johnson	3,600
Rath	500
Bidwell Park	[1] 5,400
Pershall	900
Oroville	800
Davis campus	2,800

Most of the infestations were near Chico. At Oroville, about 20 miles from Chico, eight city blocks were infested. At Davis, approximately 100 miles south of Chico, in a University of California experimental planting,

[1] As of December 1951, inspection not completed.

about 15 acres were infested. A great deal of host material had been shipped from Davis to growers throughout the State, but no infested plants originating from this infestation were found outside the Davis orchard and nursery. No scales were found in the University's orchard at Winters, although much material was interchanged between Davis and Winters. All the infestations appear to have originated from movements of infested host material from the Plant Garden and all except the Davis infestation probably date back to 1930 or before.

Two types of spread within the infested area are illustrated in figure 5. In the Johnson area (fig. 5, *A*) the infestation probably originated with the

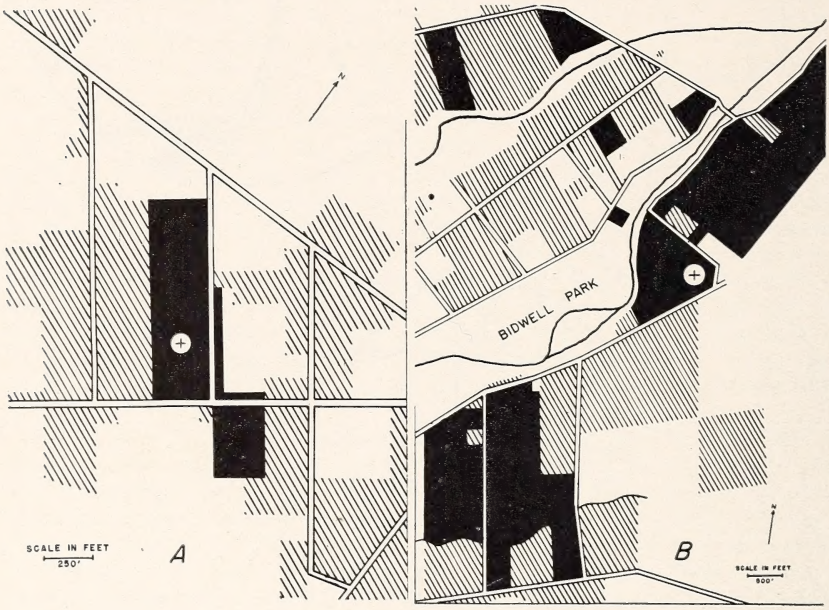

FIGURE 5.—Maps of infested areas: *A*, Johnson; *B*, Bidwell Park. Infested properties are shown in black; noninfested host plantings with hatching. Probable origin of the infestation is shown by cross in white circle.

planting of an infested nectarine tree from the Plant Garden in 1927, before the presence of the scale was known. The infestation was heavy in parts of this orchard when it was discovered and was placed under a spray program in 1941. The spread was limited to contiguous properties. Wind was the chief, perhaps the only, agent of spread. In all but one of the other infested areas the spread was of this type.

In the Bidwell Park area (fig. 5, *B*) the infestation probably started on a property on which a great deal of material from the Plant Garden was planted before 1929. This and other properties were heavily infested when the scale was discovered on them in 1949. In the meantime the scale had spread to other orchards without becoming established on many properties nearer to the source of infestation. Birds and insects, as well as wind, may have been responsible for some scattering of infestation in this area.

Treatment

OIL SPRAYS

At the beginning of the project in 1941, all infested properties were sprayed with oil as soon as discovered. The early program included a winter spray containing 3 to 3.5 percent of oil, and spring and late summer sprays containing 1.75 to 2 percent. Sometimes a second spring spray was applied to heavily infested trees. Light-medium or medium oil with a minimum unsulfonated residue of 92 percent was used. It was first planned as a holding program to minimize the danger of spread until more was known about the size of the infested area and the biology of the scale.

The first application reduced the infestation considerably, and there was some reason to hope that a continued oil-spray program might eradicate the scale. However, after a certain level of infestation was reached, spraying caused no further reduction. Scales that were exposed to spray seemed easy to kill, but there were always scales in deep crevices in the bark and other protected places that could not be reached by oil spray. The addition of DDT or rotenone to the oil failed to increase the kill appreciably. The addition of parathion to oil sprays greatly increased their effectiveness, but 3 applications of a spray containing 1.75 to 3 percent of light-medium oil plus 1 pound of 25-percent parathion per 100 gallons of oil did not eradicate the scale.

FUMIGATION

As soon as it was evident that the scale could not be eradicated with oil sprays, fumigation with hydrocyanic acid was tried. It seemed likely that uniform distribution of high, sustained concentrations of this gas would be necessary to reach the scales in protected places with a lethal dose. In 1942 the possibility of using gastight tents and hydrocyanic acid applicators equipped with blowers to insure improved distribution and retention of gas used in citrus fumigation, were being studied at the Whittier (Calif.) laboratory of the Bureau of Entomology and Plant Quarantine. Findings in this research were applied in the Hall scale project.

In preliminary tests in February 1943 trees were fumigated with 54 ml. of liquid hydrocyanic acid per 100 cubic feet under nearly gastight and semigastight tents. The fumigant was introduced with a blower applicator. Between March and September about 50,000 scales were examined, and all were dead.

These results indicated that fumigation with gastight tents might eradicate the scale. Such questions as the best dosage from the standpoint of effectiveness and tree tolerance, diurnal and seasonal time of fumigation, andlength of exposure were then investigated. Finally, techniques were developed for handling high concentrations of residual gas and for covering large trees having many pruning ends and fruit spurs, without causing excessive damage to the tents.

On the basis of these tests, it was decided to use a dosage of 40 cc. of liquid hydrocyanic acid per 100 cubic feet under gastight tents for 50 minutes, to make the fumigations in the daytime during the winter when the host trees were dormant, and to use suction blowers to evacuate the residual gas before removing the tents from treated trees.

Covering dormant deciduous trees with fumigation tents is much more difficult than covering citrus trees. To avoid tearing the tents in moving them over trees lacking a protective shell of foliage, it is necessary to lift

the tent off one tree and lower it onto the next rather than attempt to slide it off and on. On most of the trees this could be done only with mechanical tent pullers. The pullers that proved most satisfactory for this purpose were made with long booms mounted on surplus army weapon or personnel carriers (fig. 6). The largest fumigation booms reached to a height of 50 feet. Some of the steps in covering a tree are shown in figures 6 and 7.

FIGURE 6.—*A*, tent pullers constructed on surplus army personnel carriers; *B*, pulling a tent over a tree to be fumigated.

FIGURE 7.—*A*, covering a tree; *B*, removing the tent from a fumigated tree.

The tents were made of cloth with a plastic coating. The first tents did not remain gastight through one season. A local coating firm assisted in developing a mixture that could be applied with a brush each year. With the cooperation of several coating companies tents were gradually improved, as shown by the following average gas losses between 5 and 40 minutes after introduction of the gas:

	Percent
1946–47	52
1947–48	29
1948–49	18
1949–50	9
1950–51	8

Fabrics tried for tents included various cottons, glass, and nylon. Coated nylon has been the most satisfactory from the standpoint of weight and strength, but not until 1949 was a coating on nylon obtained that would go through a season without showing some deterioration. Tents obtained

FIGURE 8.—Gas applicator in place for introduction of hydrocyanic acid.

in that year have been used two seasons without showing any gas leakage.

The gas applicators used in the early work were similar to those described by Fulton and Nelson (*6*). Later models incorporated improvements made by Yust (*13*) (fig. 8). Tree volumes were calculated from the distance over

FIGURE 9.—Evacuating residual hydrocyanic acid gas from a tent at end of exposure period.

and around the tree according to the formula given by Quayle (*12*, p. 505)[4] and without the correction for leakage dependent on the surface-volume ratio which is used in citrus-fumigation practice.

A gas evacuator (fig. 9) developed from one described by Fulton and Nelson (7) consisted of a large blower which sucked the air from beneath the tent and blew it upward above the danger level for the fumigators. As a rule the tents were evacuated for about 1 minute for each 1,500 cubic feet of tree volume. This was sufficient to remove about 80 percent of the residual gas and to permit moving the tent on to the next tree without undue hazard to the crew.

Gas samples were taken regularly by a procedure common in citrus fumigation (Fulton and coworkers 5). These samples served as a check on porosity of fabrics, human errors and mechanical failures, and evacuation efficiency. The objective was to maintain a minimum average concentration of 6 mg. per liter; whenever a tent showed enough leakage to cause the average to fall below this figure, it was withdrawn from use. In the 1949–50 season the average gas concentration in 140 trees sampled was 8.2 mg. per liter; only 4 concentrations were less than 6 and none less than 5 mg. per liter.

Factors that limit fumigation are tree dormancy and weather conditions. Almonds are relatively tolerant of hydrocyanic acid from early in October until about the middle of January. Other hosts can be fumigated with little injury over a longer period, generally until about the end of February. However, the weather may get too warm to continue treatment during October. An air temperature of 85° F. has been set as the upper limit, to insure the safety of the operators—hydrocyanic acid boils at about 79°—and to decrease the possibility of tree injury. Tests showed that low temperatures did not interfere with the vaporization and distribution of the hydrocyanic acid. Concentrations of the gas were as high at 29° as at higher temperatures. However, no fumigation was done when there was ice on the trees, because the ice would prevent the gas from reaching the scale.

Wind did not affect the gas concentration under gastight tents, and fumigation was continued until the wind was strong enough to raise the tent edges. In the presence of wind, the edges were covered with dirt or held down by canvas tubes filled with sand. Fortunately, with this procedure the wind velocity that would raise the edge of the tents would also prevent the movement of tents from tree to tree.

About 800 trees were used as the first block on which the effectiveness of routine treatments was tested. This block included some of the most heavily infested trees. The first fumigations were made in January and February 1945. Mortality counts between February and May revealed no live scales, but late in the summer, after there had been time for build-up from any survivors, 19 trees with live scales were found. There were no survivors after the second or third fumigation. Search for scales on current growth and fruit late in the summer or early in the fall has been the standard method of checking results of the preceding winter's fumigation. In another orchard, also heavily infested, 5 trees of 189 examined were found infested after the first fumigation and none after the second. In all other cases no live scales were found after one fumigation.

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[4] This reference contains a typographical error. The correct formula is $\frac{C^2}{4\pi}\left(\frac{O}{2}-C(0.144)\right)$.

The program specified that three annual fumigations of each property should be given after the last live scales had been seen, and intervening spring and summer oil sprays as a supplementary treatment. The only exception was in the first test block of 800 trees. No oil sprays were made after this block had been fumigated, because of the possibility that they might decrease the chance of finding survivors, and only two fumigations were made after the last live scales had been found. Intensive inspection for 3 years since the last fumigation has not shown any scales. They were probably eradicated in this block with a somewhat weaker program than elsewhere.

By the spring of 1952 the treatment program had been completed on properties containing about 22,000 hosts, and about 2,800 hosts at Davis had been removed by the University of California. Properties containing about 4,600 hosts in the Bidwell Park and Pershall areas, representing infestations found during 1950, 1951, and 1952, were still under treatment. The known infestations in 1952 were limited to these areas.

After treatment was discontinued, properties were placed on an inspection basis for annual checks for surviving scales. Thus far, no live scales have been found on any properties after the fumigation program has been completed.

SUMMARY

The Hall scale (*Nilotaspis halli* (Green)) was first discovered in the United States at Chico, Calif., in 1934. In the United States it has been found only in California, in Chico, and in 2 localities within 100 miles of that city.

Since an attempt to eradicate the scale after its first discovery was unsuccessful, a more comprehensive eradication project was organized in 1941, with the U. S. Bureau of Entomology and Plant Quarantine and the California Department of Agriculture cooperating.

Plants found infested in California are limited to the genera *Prunus* and *Amygdalus* and the shrub *Spireae veitchii*. Additional hosts reported from other countries include *Pyrus*, *Malus*, *Cydonia vulgaris*, and *Cerasus*. Preferred hosts include almond, peach, plum, nectarine, and prune. Scales infest all parts of the hosts and cause conspicuous blotches on some fruit.

The first crawlers emerge late in March or early in April, but emergence continues until about the middle of October. There is at least a partial second generation in the summer. Only females are found during the winter months.

Inspection showed infestations at Oroville and Davis, and at five separate areas near Chico. Infested properties contained about 29,000 host plants. Infestations in the different areas were probably established by movements of infested host material. Spread within the areas appears to have been by wind and other agencies, such as birds and insects.

Oil sprays reduced the scale population but did not eradicate it. A method of fumigation with hydrocyanic acid gas in gastight tents over the plants was developed. Trees were fumigated with 40 cc. of liquid hydrocyanic acid per 100 cubic feet for 50 minutes in the daytime in the dormant season. The gas was introduced with a blower applicator and most of it was evacuated with a large blower before the tents were removed. Tents made of plastic-covered cloth were transferred from tree to tree with especially designed pullers.

The treatment program consisted of three annual fumigations after the last live scale had been seen, supplemented by spring and summer oil sprays. By the spring of 1952 this program had been completed on properties containing about 22,000 host plants. Live scales were found in only two orchards after the first fumigation, and in none after the second. After completion of the treatment program, previously infested properties were repeatedly reinspected.

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